Decay in tops killed by Douglas-fir Tussock Moth in the Blue Mountains

usda douglas-fir tussock moth research & development program

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Contents

METRIC EQUIVALENTS

1 cubic inch	= 16.387 064 cubic cm
1 inch	= 2.54 cm
1 foot	= 0.3048 m
1 cubic foot	= 0.02832 m^3
1 acre	= 0.4047 ha
Breast height = 4.5 feet	= 137.2 cm

ACKNOWLEDGMENT

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DECAY IN TOPS KILLED BY DOUGLAS-FIR TUSSOCK MOTH IN THE BLUE MOUNTAINS

Reference Abstract

Aho, Paul E., Boyd E. Wickman, and Lee Roe.
1979. Decay in tops killed by Douglas-fir tussock moth in the Blue Mountains. USDA For. Serv. Res. Pap. PNW-250, 22 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Incidence of infection by fungi and decay loss was negligible in Douglas-firs with tops killed by tussock moth or bark beetle attack. Regardless of the cause of top-kill, both the percentage of grand firs infected and the associated decay volumes significantly increased with increasing basal diameter of dead tops. Severity of decay was not related to age of top damage. Decay was most severe when both bark beetles and wood borers attacked dead tops.

KEYWORDS: Decay (wood), insect damage (-forest, top-kill, defect indicators (wood quality), Douglas-fir tussock moth, *Orgyia pseudotsugata*.

RESEARCH SUMMARY

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Douglas-firs and grand firs which were top-killed during tussock moth infestations approximately 4, 10, and 28 years ago were examined for incidence and extent of stem decay. Only 18 Douglas-firs with killed tops were found. Of 14 Douglas-firs with dead tops attributed to the tussock moth, only one top was infected and decay loss was small.

Of 149 grand firs studied, 92 were considered to be top-killed as a result of defoliation by the tussock moth or associated attack by bark beetles, mainly *Scolytus ventralis*. Bark beetles were the main cause of top-kill not related to tussock moth damage. The same factors influenced incidence and extent of decay associated with top-kills caused by either tussock moth defoliation or other agents. They include diameter at the base of dead tops and presence of secondary insect attack. Severity of decay was not related to years since top-kill--most likely because salvage logging and bark beetle attacks removed the most defective trees from the oldest infestation areas. Regardless of the cause of top-kill, both the percentage of grand firs infected and the associated decay volumes increased with increasing basal diameter of dead tops. The incidence of infection

and amount of decay were lowest in tops killed by defoliation only. In all study areas, decay was most severe when both bark beetles and wood borers attacked dead tops.

Unidentified fungi caused 85 percent of all decay columns and 76 percent of the total cubic decay volume associated with tops killed by all causes. Imperfect fungi and bacteria or yeasts, possibly associated with beetle attacks, were mainly isolated from decay columns caused by unidentified hymenomycetous fungi. *Amylostereum chailletii*, *Fomitopsis pinicola*, *Echinodontium tinctorium*, *Pholiota* sp., and *Stereum sanguinolentum* were isolated from decays associated with killed tops.

Two methods are given for making defect deductions for grand firs with tops killed by the tussock moth or other agents. Defect percentages of gross merchantable Scribner board-foot and cubic-foot volumes and average decay extent below the base of dead tops are tabulated by age and basal diameter of dead tops. Statistical tests indicate that these estimating methods may result in low accuracy, thus they should be used only as general guidelines by timber cruisers in the Blue Mountains.

Introduction

During the period 1971-74, the Douglas-fir tussock moth (*Orgyia pseudotsugata* McDonnough) extensively damaged timber on more than 800,000 acres in Oregon, Washington, and Idaho (Graham et al. 1975). Extensive top-killing of Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco) and grand fir (*Abies grandis* (Dougl.) Lindl.) occurred on 292,000 acres of moderately damaged timber, and some top-kill was scattered through 419,000 acres of lightly damaged stands (Graham et al. 1975, Wickman 1978). Decay entering through killed tops may increase timber loss following tussock moth infestation. Forest managers need to know the progress of decay to plan utilization of trees damaged by defoliation. This information is presently unavailable for grand fir and Douglas-fir in the Blue Mountains of eastern Oregon and Washington.

Although "wetwood" was common (Wickman and Scharpf 1972), little deductible defect was associated with white fir (*Abies concolor* (Gord. & Glend.) Lindl.) in California 33 years after top-killed by the tussock moth. This information may not be applicable to tree species in the Blue Mountains, because decay varies widely between regions (Wagener and Davidson 1954). Johnson and Hadfield[1/] examined Douglas-firs and grand firs top-killed by the tussock moth during an epidemic from 1963-65 in the Kings Mountain area, Burns Ranger District, Malheur National Forest, Oregon. Their sample was too small, however, to apply top-kill and associated decay information to forest management.

Our objectives were to assess the impact of decay entering grand fir and Douglas-fir through tops killed by the tussock moth or secondary beetle attack up to 3 years after the infestation in the Blue Mountains ended. This assessment of pathology included frequency of infection, extent of decay, identification of decay organisms, and development of equations for use in estimating the amount of decay associated with dead tops.

Methods

SELECTION OF STUDY AREAS AND TREES

Grand firs and Douglas-firs with dead tops evidenced by spike (fig. 1), bayonet (fig. 2), forked (fig. 3), or crooked (fig. 4) tops (Wickman and Scharpf 1972) were selected for study in three areas in the Blue Mountains known to have been severely attacked by the tussock moth in the past. Nine localities were sampled near Fox Prairie and Round Mountain, Umatilla National Forest. Sample trees were selected near plots which were installed to study damage caused during the 1972-74 tussock moth infestation (fig. 5).

1/ Johnson, David W., and James S. Hadfield. 1975. Defect in Douglas-fir and grand fir top-killed by the Douglas-fir tussock moth. USDA For. Serv., Region 6, Div. of State and Private Forestry. Mimeo, 10 p.

Figure 1.--A. Grand fir with 3-year-old dead (spike) top. B. Cross-sections at various heights in the same tree showing associated discoloration and decay.

Figure 2.--Bayonet top on a grand fir resulting from death of original leader by tussock moth defoliation. Note that decay is confined to the dead top.

Figure 3.--A. Grand fir with a forked top caused by tussock moth defoliation 9 years ago. B. Cross-section at the base of a fork showing the buried original leader.

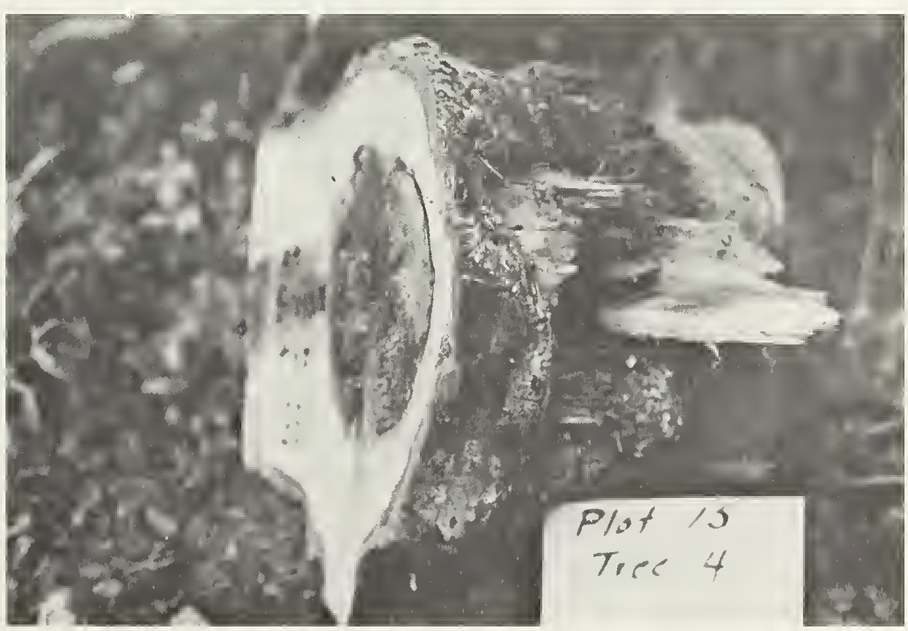

Figure 4.--Cross-section at a crooked top resulting from death of the original leader due to tussock moth defoliation. The crook occurred when a lateral branch gained dominance, thus becoming the new top. Note the decay associated with the old broken leader.

Figure 5.--Mortality and dead tops caused by Douglas-fir tussock moth defoliation during the 1972-74 infestation in the Blue Mountains.

Many trees with dead tops were available for study in these localities, therefore, trees were selected with a wide range of ages, diameters at breast height, and diameters at the base of dead tops.

Sampling took place at eleven localities near King Mountain, Malheur N.F.--the site of a 1963-65 tussock moth outbreak. Seven stands were sampled near Long Meadows Guard Station, Umatilla N.F. where a severe tussock moth infestation occurred from 1945 to 1947. Past salvage logging had removed many top-damaged trees in the two older infestation areas. Trees sampled in these areas were usually selected as encountered, unless we could determine by observation from the ground that a dead top was caused by recent bark beetle attacks.

Dead and deformed tops of sample trees were examined to establish the year in which the tops were killed (Wickman and Scharpf 1972, also see footnote 1) in order to attribute the probable cause of death to defoliation, secondary insect attack, or other causes. Since trees weakened by defoliation are susceptible to attack by beetles for several years (Wickman 1963), tops killed by secondary insects during, or within 3 years after the known infestation, were considered tussock moth damaged (fig. 6). An exception was in the oldest epidemic in the Long Meadows area, where trees with tops killed from 21-35 years ago (instead of 26-31 years) were considered damaged by tussock moth defoliation. The age range for this infestation was expanded because of the difficulty and probable errors in aging older dead tops. Some of the most recently killed tops probably originated during a spruce budworm outbreak which occurred in the early 1950's.

In the Fox Prairie and Round Mountain localities, the site of the most recent epidemic, 41 grand fir trees with dead tops associated with

Figure 6.--Secondary bark beetle attack of grand fir weakened by tussock moth defoliation in the King Mountain infestation from 1963-65.

tussock moth defoliation were studied; 37 in the King Mountain area; and only 14 in the Long Meadows area (table 1). Trees found to be top-killed either before or more than 3 years after the infestation occurred in a given locality were studied for comparative purposes (table 1). Top-killing in these trees was considered to be caused by other (unknown) agents.

TREE DISSECTION AND MEASUREMENT

Selected trees with top-damage were felled at a stump height of 1 foot and dissected into 16-foot logs to a top d.i.b. of 4 inches for cubic

Table 1--*Numbers of grand fir study trees top-killed before, during, and after three Douglas-fir tussock moth infestations in the Blue Mountains*

Study locality	Date of tussock moth outbreak	Age of top-kill	Trees with tops killed: Before outbreak	Within 3 years after outbreak	More than 3 years after outbreak
		Years	- - - - - - -Number	- - - - - - -	
Fox Prairie and Round Mountain	1972-74	2-5	3	41	0
King Mountain	1963-65	8-13	13	37	14
Long Meadows	1945-47	[1] 21-35	6	14	21

[1] To be considered as tops killed by tussock moths, the age should range from 26-31 years. The age range for this infestation was expanded, however, because of the difficulty of accurately aging older dead tops.

volume measurement. Board-foot volumes of trees 11-in d.b.h. and larger were measured to a top d.i.b. of 6 in. Disks were cut immediately above, at the base of, and below the damage. Ring counts were made at these points to determine when the top was killed. D.b.h., tree age at stump height, and location and description of decay indicators were noted for each tree. Logs were dissected further to measure the extent of decay associated with top-damage or other indicators.

We recorded the type of top-damage (i.e. spike top, broken top, fork, crook, etc.), and the height to and basal diameter of the killed top. Also recorded was the length of the dead top, the length and diameter of any new leaders, the year of top-kill, the extent of decay below and above the base of killed tops, and the presence or absence of secondary insect attack.

A program (PACUL) was developed at the Pacific Northwest Forest and Range Experiment Station to compute volumes of trees and decays. Cubic-foot volumes of logs and decay columns were calculated by the Smalian formula. No arbitrary cull rules were used in cubic-volume measurement. Gross board-foot volumes of logs in trees 11-inch d.b.h. and larger were computed by the Scribner log rule. Board-foot deductions for decay, shake, and frost cracks were made by the squared-defect method. In board-foot measurements, logs more than two-thirds defective were considered totally cull.

ISOLATION AND IDENTIFICATION OF DECAY FUNGI

Culture blocks, approximately 3 in^3 (7.6 cm^3) in size, were taken from disks cut at the base of and just below the dead top in most trees. These samples were always taken when discoloration or decay was present. Additional culture blocks were taken at various intervals from long decay columns. The blocks were placed in plastic bags and stored in an ice chest until taken to the laboratory.

In the laboratory, the blocks were split with a sterile chisel, and small wood chips were removed from freshly exposed discoloration or decay and placed on 2.5 percent malt agar slants in culture tubes. Inoculated tubes were incubated at room temperature.

The types (hymenomycetes, fungi imperfecti, and bacteria and yeasts) of microorganisms which had been isolated were noted. The hymenomycetous fungi were identified by Frances L. Lombard, Center for Mycology Research, Forest Products Laboratory, Madison, Wisconsin.

STATISTICAL METHODS

Regression and covariance analyses were used to test the relationships between cubic- and board-foot decay (as a percent of gross merchantable tree volumes) and top-kill age, base diameter of dead tops, presence of secondary insect attack, and to derive equations which can be used to predict the extent of defect associated with grand fir dead tops. The equations were used to tabulate defect as (1) percentages of gross merchantable tree cubic-foot and Scribner board-foot volumes, and (2) ex-

tent of decay (length of decay column) below the base of dead tops by age and basal diameter of killed tops.

Results and Discussion

We originally planned to study more Douglas-firs with tussock moth-killed tops than we did. It was, however, difficult to locate Douglas-firs with killed tops, at least in the areas where the oldest outbreaks had occurred. Furthermore, when Douglas-firs with killed tops were located, we found very little, if any, associated decay. Apparently, severely defoliated Douglas-firs were killed by bark beetles, other agents, or had been logged. Only 18 Douglas-firs with killed tops were felled and studied in the three areas of infestation. Only one (7 percent) of 14 trees top-killed by the tussock moth was infected with decay fungi, and less than 1 percent of the total cubic- or board-foot volume was lost to decay.

Basic data for 149 grand firs, from the three study areas with tops killed by the tussock moth and by other agents, are summarized in table 2. Ninety-two of the trees were considered to be damaged by the tussock moth. Decay associated with top-kill caused by other agents in each area of infestation was significantly ($P = <0.01$) greater than decay associated with tussock moth-killed tops, probably because dead tops killed by other agents were, on the average, older and had larger basal diameters. Decay volume not associated with killed tops was also significantly greater in grand firs top-killed by other agents than by the tussock moth (table 2).

DECAY IN RELATION TO AGE OF TOP-KILL

Decay associated with top-damaged trees, regardless of cause, was not significantly related to age of top-kill. We surmise that frequent salvage logging and repeated bark beetle attacks in the two older (King Mountain and Long Meadows) epidemic areas removed the more seriously damaged trees, thus, our sample mainly included the less damaged, less defective trees.

DECAY IN RELATION TO DIAMETER AT THE BASE OF DEAD TOPS

Cubic- and board-foot decay volumes associated with dead tops of grand firs from the three study areas combined, regardless of cause of the top-kill, increased significantly ($P = <0.05$) with increasing basal diameter of dead tops (table 3). The same relationship held for trees from each individual study area. Decay volumes were negligible in trees with tussock moth-killed tops with less than 2-in diameter at the base (fig. 7).

Wickman and Scharpf (1972) found no decay in white fir trees with killed tops less than 8-in diameter in the Mammoth Lakes area in California. Decay associated with tops killed by other agents was significantly greater ($P = <0.01$) than that associated with tops killed by the tussock moth (tables 2 and 3). Diameter at the base of dead tops can be useful to estimate the volume and extent of associated defect.

Table 2--*Basic data for grand firs top-killed by the Douglas-fir tussock moth and other agents from three localities in the Blue Mountains*

Cause of top-kill	Age range of top-kills (years)	Tree basis (No.)	Total top-kills infected (%)	Average: Tree D.b.h. (in)	Average: Tree Age (yr)	Average: Top-kill Diameter at base (in)	Average: Top-kill Age (yr)	Cubic-foot volume associated with top-kill: Gross	Cubic-foot: Decay	Cubic-foot: Decay (%)	Board-foot volume associated with top-kill: Gross	Board-foot: Decay	Board-foot: Decay (%)	Decay not associated with top-kill: Cubic feet Total	Cubic feet Percent of gross	Board feet Total	Board feet Percent of gross
Tussock moth	2-35	92	75.0	14.2	100	4.7	9.6	3,684.0	176.6	4.8	18,977	1,053	5.5	191.7	5.2	1,435	7.6
Other agents	4-68	57	80.7	14.8	115	5.3	17.8	2,428.8	223.7	9.2	12,384	1,425	11.5	320.9	13.2	2,354	19.0
Total or average	2-68	149	77.2	14.4	106	5.0	12.7	6,112.8	400.3	6.5	31,361	2,478	7.9	512.6	8.4	3,789	12.1

Table 3--*Decay in relation to basal diameter of grand fir tops killed by the tussock moth and other agents in all study areas combined*

Diameter at base of dead top (in)	Cause of dead top	Tree basis (No.)	Average: Diameter at base of dead top (in)	Average: Tree D.b.h. (in)	Average: Tree Age (yr)	Trees infected (%)	Cubic-foot volume: Gross	Cubic-foot volume: Decay (%)	Board-foot volume: Gross	Board-foot volume: Decay (%)	Decay extent below base of dead top (ft)
0-2.0	Tussock moth	21	1.0	10.5	91	14.3	345.0	0.02	1,283	0.0	0.3
	Other	11	1.4	12.9	95	45.5	282.8	2.7	1,157	2.3	3.3
	All combined	32	1.1	11.3	92	25.0	627.8	1.2	2,440	1.1	1.3
2.1-4.0	Tussock moth	15	3.0	10.3	88	86.7	225.1	2.8	763	1.6	6.7
	Other	17	3.2	13.0	115	82.4	565.8	2.8	2,700	6.0	5.8
	All combined	32	3.1	11.7	102	84.4	790.9	2.8	3,463	5.1	6.2
4.1-6.0	Tussock moth	29	5.1	14.4	97	89.7	1,081.7	2.4	5,122	2.0	7.3
	Other	9	5.1	13.2	95	100.0	244.6	10.8	1,141	21.8	8.2
	All combined	38	5.1	14.1	96	92.1	1,326.3	3.9	6,263	5.6	7.5
6.1-8.0	Tussock moth	15	7.0	16.3	102	93.3	804.6	7.2	4,392	5.9	9.8
	Other	12	7.0	15.4	120	91.7	379.3	17.8	1,698	22.3	17.2
	All combined	27	7.0	15.9	110	92.6	1,183.9	10.6	6,090	10.5	13.1
8.1-10.0	Tussock moth	10	8.9	20.8	124	100.0	877.7	7.8	5,204	11.2	11.6
	Other	3	9.3	19.3	173	100.0	212.9	13.2	1,172	15.4	16.7
	All combined	13	9.0	20.4	135	100.0	1,090.6	8.9	6,376	12.0	12.8
10.1+	Tussock moth	2	12.8	26.6	215	100.0	349.9	5.2	2,213	4.5	9.0
	Other	5	14.0	26.5	174	80.0	743.4	10.5	4,516	9.4	16.4
	All combined	7	13.6	26.5	186	85.7	1,093.3	8.8	6,729	7.8	14.3

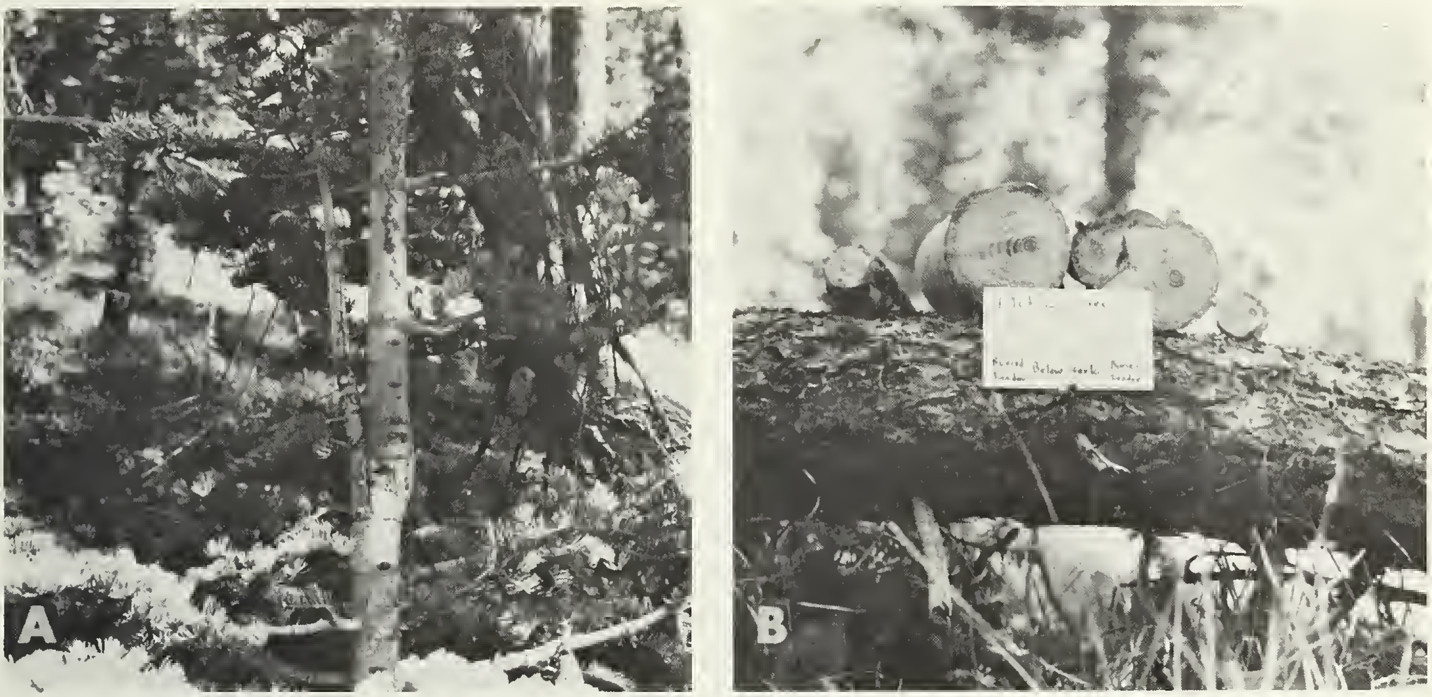

Figure 7.--A. Grand fir with tussock moth-killed top (9 years old) with a basal diameter less than 2 in. A lateral branch has become the new leader. B. The buried leader is discolored but not decayed. There is no discoloration or decay in the new leader.

DECAY IN RELATION TO SECONDARY INSECT ATTACK

Tops killed by tussock moth defoliation or other agents and also attacked by bark beetles and wood borers had high incidences of infection by fungi and decay was significantly ($P = <0.05$) more extensive than in tops killed only by defoliation (table 4). Apparently, these beetles are vectors of decay fungi or create favorable infection sites and conditions for decay. In all study areas, decay was most severe when both bark beetles and wood borers attacked dead tops (table 4). Bark beetles were associated with shallow infections of the outer sapwood and wood borer attack with infection and decay deep in the heartwood.

A high proportion (nearly 3/4) of trees with dead tops were attacked by bark beetles, either primarily or secondarily to tussock moth defoliation (table 5). Gallery patterns indicated that *Scolytus ventralis* Lec. was the bark beetle most frequently attacking killed tops. More study trees were attacked by bark beetles in the Fox Prairie-Round Mountain (77.3 percent of the total trees) and King Mountain (84.4 percent) areas, sites of the 2- to 5- and 8- to 13-year epidemics, respectively, than in the older infestation area at Long Meadows (56.1 percent). Wickman (1978) found that proportion of dead tops attacked by bark beetles increased with age of tussock moth infestation. Results in our study probably reflect the effects of salvage logging in the Long Meadows area. Severely damaged trees have been removed in logging operations which have frequently occurred in this area.

Table 4--*Decay associated with tops killed by the tussock moth and other agents in relation to secondary insect attack for grand firs from all study areas*

Secondary insect attack	Cause of dead top	No. of trees	Percent with decay	Average Tree		Cubic-foot volume		Board-foot volume		Average decay extent below (ft)	Average diameter at base of dead top (in)
				D.b.h. (in)	Age (yr)	Gross	Decay (%)	Gross	Decay (%)		
None	Tussock moth	21	28.6	11.4	85	435.1	0.3	1,741	0.7	1	1.4
	Other	11	54.5	12.6	108	265.4	1.7	963	1.6	2	1.9
	Both combined	32	37.5	11.8	93	700.5	0.8	2,704	1.0	1	1.6
Bark beetles	Tussock moth	7	71.4	11.4	101	157.0	2.2	697	1.6	5	3.9
	Other	8	75.0	12.0	102	159.2	2.4	471	3.2	6	3.1
	Both combined	15	73.3	11.7	102	316.2	2.3	1,168	2.2	5	3.5
Wood borers	Tussock moth	3	66.7	8.9	118	34.8	5.2	68	0.0	4	3.2
	Other	3	66.7	8.4	113	26.9	26.0	-	-	14	4.1
	Both combined	6	66.7	8.7	115	61.7	14.3	68	0.0	9	3.6
Bark beetles and wood borers	Tussock moth	61	91.8	15.8	105	3,057.1	5.6	16,471	6.2	9	6.0
	Other	35	91.4	17.1	124	1,977.3	10.5	10,950	12.7	13	6.9
	Both combined	96	91.7	16.3	112	5,034.4	7.5	27,421	8.8	10	6.3

Bark beetle attack was not restricted to dead tops. More than 30 percent of all trees with dead tops were attacked by bark beetles both in the dead tops and in patches along the living boles (table 5). The extent of bark beetle attack below the base of dead tops increased with age of top-kill regardless of cause (table 5).

FUNGI AND OTHER MICROORGANISMS ASSOCIATED WITH DECAY

Slightly more than 85 percent of all infections and more than 76 percent of the total cubic decay volume associated with dead tops were caused by unidentified fungi (table 6). Attempts to isolate decay fungi resulted mainly in isolation of imperfect fungi (61.9 percent of 357 attempts) and bacteria or yeasts (20.2 percent). Unidentified hymenomycetes (decay fungi) were isolated in 3.4 percent of the 357 isolation attempts (table 6). Apparently, imperfect fungi and bacteria, commonly associated with bark beetles and probably wood borers, are much faster growing on culture medium than decay fungi, excluding them. Wickman and Scharpf (1972) also had difficulty in isolating decay fungi from decay (incipient) associated with white fir dead tops. Imperfect fungi and bacteria were the most numerous microorganisms isolated from discolorations associated with dead tops of grand fir in the King Mountain area, Burns Ranger District (see footnote Hadfield 1975).

Amylostereum chailletii (Pers. ex Fr.) Boid., *Fomitopsis pinicola* (Swartz ex Fr.) Karst., *Echinodontium tinctorium* Ell. & Ev., *Pholiota* sp., and *Stereum sanguinolentum* (Alb. & Schw. ex Fr.) were isolated from decays associated with dead tops (table 6). The most extensive decay columns were caused by *F. pinicola*.

The Indian paint fungus, *E. tinctorium*, decay columns may have resulted from reactivation of dormant infections of this fungus by death of the tree top (Etheridge et al. 1976).

Twenty-three decay columns were found associated with infection courts other than dead tops. Cause of decay was not identified in nearly 40 percent of these columns. Bacteria or yeasts and imperfect fungi were the only organisms isolated from them. The Indian paint fungus, *E. tinctorium*, caused slightly more than 30 percent of the decay columns, but nearly 90 percent of the total cubic decay volume. *Fomitopsis annosa* (Fr.) Karst. was isolated from six root and butt rot columns in the study trees.

Many additional isolations were attempted from trees that did not have decay or discolorations, other than wetwood, associated with dead tops. Most of these attempts did not yield organisms. Bacteria or yeasts and imperfect fungi were the only organisms isolated from wetwood (fig. 8) and clear wood. Wickman and Scharpf (1972) and Johnson and Hadfield (see footnote 1) had similar results when isolating from wetwood.

ESTIMATING DEFECT ASSOCIATED WITH DEAD TOPS

Defect factors are presented as a guide to timber cruisers and others interested in predicting losses from decay after tussock moth infestations have declined. They are presented as percentages of gross merchantable

Table 5--*Grand firs with dead tops infested with bark beetles in the killed portion only and in both the dead and living tree bole and extent of attack below the base of dead tops*

Study area	Cause of dead top	Total trees with dead tops	Trees attacked by bark beetles	Proportion of all trees attacked by bark beetles			Average extent of bark beetle attack below base of dead top
				Total	Restricted to dead top	Attack in dead top and living bole	
		- - - Number	- - - -	- - - - - - - -	Percent - - - -	- - - - - - - -	- - Feet - -
Fox Prairie and Round Mountain	Tussock moth	41	31	75.6	61.0	14.6	27.3
	Other	3	3	100.0	33.3	66.7	22.5
	All combined	44	34	77.3	59.1	18.2	26.1
King Mountain	Tussock moth	37	30	81.0	32.4	48.6	29.3
	Other	27	24	88.9	55.6	33.3	41.8
	All combined	64	54	84.4	42.2	42.2	33.4
Long Meadow Guard Station	Tussock moth	14	7	50.0	21.4	28.6	43.0
	Other	27	16	59.3	33.4	25.9	48.6
	All combined	41	23	56.1	29.3	26.8	46.5
All combined	Tussock moth	92	68	73.9	43.5	30.4	30.8
	Other	57	43	75.4	43.8	31.6	42.3
	All combined	149	111	74.5	43.6	30.9	35.3

Table 6--*Fungi and other micro-organisms from decays associated with top damage of grand fir*

Apparent cause of decay	Trees	Decay columns	Average decay volume		Decay volume		Results of cultural isolation attempts				
			cu ft	bd ft	cu ft	bd ft	Total isolation attempts	Hymeno-mycetes	Fungi imperfecti	Bacteria or yeasts	No growth
	Number	Percent of total			- Percent -		Number	- - - - - - Percent of total - - - - - -			
Unidentified	97	85.1	3.0	24	76.4	69.0	357	3.4	61.9	20.2	14.5
Amylostereum chailletii (Pers. ex Fr.) Boid.	5	4.4	1.5	5	1.9	0.8	23	56.5	30.4	4.3	8.8
Fomitopsis pinicola (Swartz ex Fr.) Karst.	4	3.5	15.8	140	16.4	23.3	16	50.0	37.5	12.5	0.0
Echinodontium tinctorium Ell. and Ev.	4	3.5	4.7	80	4.9	6.6	15	53.3	26.7	13.3	6.7
Pholiota sp.	3	2.6	0.5	4	0.4	0.2	8	87.5	12.5	0.0	0.0
Stereum sanguinolentum (Alb. and Schw. ex Fr.) Fr.	1	0.9	0.1	3	+	0.1	4	25.0	0.0	0.0	75.0
Total or average	114	100.0	3.4	30	100.0	100.0	423	11.6	56.5	18.2	13.7

Figure 8.--Cross-section cut from a grand fir showing wetwood associated with a dead top and bark beetle attack.

tree cubic-foot and Scribner board-foot volumes (tables 7, 8, 9, 11) and average extent of decay below the base of dead tops (tables 10, 12). Defect percentages and average decay extents derived from regression analysis are tabulated by age and basal diameter of dead tops (tables 8-12). Equations used to derive the tables are presented in table footnotes. If the equations are to be used in a computer program, consideration must be given to the fact that defect percentages or average decay extents for some combinations of age and basal diameter of dead tops can be less than zero. In these cases, provision should be made to set the percentages at zero.

Coefficients of determination (R^2) or the amount of variation in percent decay or decay extent that is explained by the variables in the equations are low (tables 7-12, footnote 1) thus values predicted by the equations will often be of low accuracy and can be used as general guidelines only. Type of secondary insect attack as an independent variable in the equations would raise coefficients of determination; however, in practice, this variable would not be useful to timber cruisers since it is usually necessary to fall and dissect trees to determine the type of secondary insect attack.

Tables 7-9 were developed from regression analysis of data for trees top-killed by the tussock moth or by secondary bark beetle attack. All trees, regardless of cause of top-kill, were used to develop tables 11-12. The first set of tables (7-9) or equations should probably be used to predict decay extent following known tussock moth infestations. The others (tables 10-12) can be used to estimate decay extent where tops are killed by any agent.

As an example, volume deductions for a grand fir tree top-killed (8 inches at the base of the dead top) by the tussock moth 10 years ago are 8.9 percent of gross merchantable cubic volume (table 7) and 8.6 percent of its Scribner volume (table 8). Average decay extent below the base of the dead top is 10.3 feet (table 9). Similar deductions can be found in tables 10-12 for trees with tops killed by other agents.

Table 7--*Defect in percent of gross merchantable cubic-foot volume for tussock moth top-damaged grand fir trees by dead-top age and diameter at the dead-top base*[1]

Dead-top age (years)	Diameter at base of dead top (inches)							
	1	2	4	6	8	10	12	14
	- - - - - - - -	- - - - - - - -	- - - - - - - -	- - - - - - Percent	- - - - - - - -	- - - - - - - -	- - - - - - - -	- - - - - - - -
1	.000	.795	2.936	5.077	7.217	9.358	11.499	13.639
2	.000	.980	3.120	5.261	7.402	9.543	11.683	13.824
3	.094	1.164	3.305	5.446	7.586	9.727	11.868	14.009
4	.279	1.349	3.490	5.630	7.771	9.912	12.052	14.193
5	.463	1.534	3.674	5.815	7.956	10.096	12.237	14.378
6	.648	1.718	3.859	6.000	8.140	10.281	12.422	14.562
7	.832	1.903	4.044	6.184	8.325	10.466	12.606	14.747
8	1.017	2.087	4.228	6.369	8.510	10.650	12.791	14.932
9	1.202	2.272	4.413	6.553	8.694	10.835	12.976	15.116
10	1.386	2.457	4.597	6.738	8.879	11.019	13.160	15.301
15	2.309	3.380	5.520	7.661	9.802	11.943	14.083	16.224
20	3.232	4.303	6.444	8.584	10.725	12.866	15.006	17.147
25	4.156	5.226	7.367	9.507	11.648	13.789	15.929	18.070
30	5.079	6.149	8.290	10.430	12.571	14.712	16.852	18.993

[1]Derived from: $Pc = -1.52967 + 0.184615\ A + 1.07035\ D$;
where, Pc = percent of gross merchantable cubic-foot volume that is cull,
A = dead-top age in years,
D = diameter at base of dead top in inches, and
$R^2 = 0.188$.

Table 8--*Defect in percent of gross merchantable Scribner board-foot volume for tussock moth top-damaged grand fir trees by dead-top age and diameter at the dead-top base*[1]

Dead-top age (years)	Diameter at base of dead top (inches)							
	1	2	4	6	8	10	12	14
	- Percent -							
1	.000	.000	.536	3.020	5.504	7.988	10.472	12.956
2	.000	.000	.885	3.369	5.853	8.337	10.821	13.305
3	.000	.000	1.234	3.718	6.202	8.686	11.170	13.654
4	.000	.000	1.583	4.067	6.551	9.035	11.519	14.003
5	.000	.000	1.932	4.416	6.900	9.384	11.868	14.352
6	.000	.000	2.281	4.765	7.249	9.733	12.217	14.701
7	.000	.146	2.630	5.114	7.598	10.082	12.566	15.050
8	.000	.495	2.979	5.463	7.947	10.431	12.915	15.399
9	.000	.844	3.328	5.812	8.296	10.780	13.264	15.748
10	.000	1.193	3.677	6.161	8.645	11.129	13.613	16.097
15	1.696	2.938	5.422	7.906	10.390	12.874	15.358	17.842
20	3.441	4.683	7.167	9.651	12.135	14.619	17.103	19.587
25	5.186	6.428	8.912	11.396	13.880	16.364	18.848	21.332
30	6.931	8.173	10.657	13.141	15.625	18.109	20.593	23.077

[1]Derived from: $Pb = -4.78014 + 0.349001\ A + 1.24197\ D$;
where, Pb = percent of gross merchantable board-foot volume that is cull,
A = dead-top age in years,
D = diameter at base of dead top in inches, and
$R^2 = 0.186$.

Table 9--*Decay extent below the base of grand fir dead tops caused by the tussock moth by dead-top age and diameter at the dead-top base*[1]

Dead-top age (years)	Diameter at base of dead top (inches)							
	1	2	4	6	8	10	12	14
	- - - - - -	- - - - - -	- - - - - -	- - - - - -	Percent	- - - - - -	- - - - - -	- - - - - -
1	.737	1.876	4.154	6.432	8.709	10.987	13.265	15.543
2	.917	2.056	4.334	6.612	8.890	11.168	13.445	15.723
3	1.097	2.236	4.514	6.792	9.070	11.348	13.626	15.904
4	1.278	2.417	4.694	6.972	9.250	11.528	13.806	16.084
5	1.458	2.597	4.875	7.153	9.430	11.708	13.986	16.264
6	1.638	2.777	5.055	7.333	9.611	11.888	14.166	16.444
7	1.818	2.957	5.235	7.513	9.791	12.069	14.347	16.624
8	1.999	3.137	5.415	7.693	9.971	12.249	14.527	16.805
9	2.179	3.318	5.596	7.873	10.151	12.429	14.707	16.985
10	2.359	3.498	5.776	8.054	10.331	12.609	14.887	17.165
15	3.260	4.399	6.677	8.955	11.233	13.510	15.788	18.066
20	4.161	5.300	7.578	9.856	12.134	14.412	16.689	18.967
25	5.062	6.201	8.479	10.757	13.035	15.313	17.591	19.868
30	5.963	7.102	9.380	11.658	13.936	16.214	18.492	20.769

[1]Derived from: $Pd = -0.581668 + 0.180221\ A + 1.13893\ D$;
where, Pd = decay extent, in feet, below the dead-top base,
A = dead-top age in years,
D = diameter at base of dead top in inches, and
$R^2 = 0.250$.

Table 10--*Defect in percent of gross merchantable cubic-foot volume for top-damaged grand fir trees, regardless of cause, by dead-top age and diameter at the dead-top base*[1]

Dead-top age (years)	Diameter at base of dead top (inches)							
	1	2	4	6	8	10	12	14
	Percent							
1	1.490	2.616	4.870	7.123	9.376	11.629	13.882	16.135
2	1.573	2.700	4.953	7.206	9.459	11.712	13.965	16.218
3	1.657	2.783	5.036	7.289	9.542	11.796	14.049	16.302
4	1.740	2.867	5.120	7.373	9.626	11.879	14.132	16.385
5	1.824	2.950	5.203	7.456	9.709	11.962	14.215	16.468
6	1.907	3.034	5.287	7.540	9.793	12.046	14.299	16.552
7	1.991	3.117	5.370	7.623	9.876	12.129	14.382	16.635
8	2.074	3.201	5.454	7.707	9.960	12.213	14.466	16.719
9	2.157	3.284	5.537	7.790	10.043	12.296	14.549	16.802
10	2.241	3.367	5.620	7.874	10.127	12.380	14.633	16.886
15	2.658	3.785	6.038	8.291	10.544	12.797	15.050	17.303
20	3.075	4.202	6.455	8.708	10.961	13.214	15.467	17.720
25	3.493	4.619	6.872	9.125	11.378	13.631	15.884	18.137
30	3.910	5.036	7.289	9.542	11.795	14.048	16.301	18.555
35	4.327	5.454	7.707	9.960	12.213	14.466	16.719	18.972
40	4.744	5.871	8.124	10.377	12.630	14.883	17.136	19.389
45	5.161	6.288	8.541	10.794	13.047	15.300	17.553	19.806
50	5.579	6.705	8.958	11.211	13.464	15.717	17.970	20.223

[1]Derived from: $Pc = 0.280501 + 0.0834417\ A + 1.12652\ D$;
where, Pc = percent of gross merchantable cubic-foot volume that is cull,
A = dead-top age in years,
D = diameter at base of dead top in inches, and
$R^2 = 0.165$.

Table 11--*Defect in percent of gross merchantable Scribner board-foot volume for top-damaged grand firs, regardless of cause, by dead-top age and diameter at the dead-top base*[1]

Dead-top age (years)	Diameter at base of dead top (inches)							
	1	2	4	6	8	10	12	14
	Percent							
1	.907	2.016	4.235	6.453	8.672	10.891	13.109	15.328
2	1.123	2.233	4.451	6.670	8.889	11.107	13.326	15.545
3	1.340	2.449	4.668	6.887	9.105	11.324	13.542	15.761
4	1.556	2.666	4.884	7.103	9.322	11.540	13.759	15.978
5	1.773	2.882	5.101	7.320	9.538	11.757	13.976	16.194
6	1.990	3.099	5.318	7.536	9.755	11.973	14.192	16.411
7	2.206	3.315	5.534	7.753	9.971	12.190	14.409	16.627
8	2.423	3.532	5.751	7.969	10.188	12.407	14.625	16.844
9	2.639	3.748	5.967	8.186	10.404	12.623	14.842	17.060
10	2.856	3.965	6.184	8.402	10.621	12.840	15.058	17.277
15	3.938	5.048	7.266	9.485	11.704	13.922	16.141	18.360
20	5.021	6.130	8.349	10.568	12.786	15.005	17.224	19.442
25	6.104	7.213	9.432	11.650	13.869	16.088	18.306	20.525
30	7.187	8.296	10.514	12.733	14.952	17.170	19.389	21.608
35	8.269	9.379	11.597	13.816	16.034	18.253	20.472	22.690
40	9.352	10.461	12.680	14.899	17.117	19.336	21.554	23.773
45	10.435	11.544	13.763	15.981	18.200	20.418	22.637	24.856
50	11.517	12.627	14.845	17.064	19.283	21.501	23.720	25.938

[1]Derived from: $Pb = -0.418516 + 0.21654\,A + 1.10932\,D$;
where, Pb = percent gross merchantable board-foot volume that is cull,
A = dead-top age in years,
D = diameter at base of dead top in inches, and
$R^2 = 0.116$.

Table 12--*Decay extent below the base of grand fir dead tops, regardless of cause, by dead-top age and diameter at the dead-top base*[1]

Dead-top age (years)	Diameter at base of dead top (inches)							
	1	2	4	6	8	10	12	14
	Percent							
1	1.911	3.153	5.638	8.122	10.606	13.091	15.575	18.060
2	2.013	3.256	5.740	8.224	10.709	13.193	15.678	18.162
3	2.116	3.358	5.842	8.327	10.811	13.296	15.780	18.264
4	2.218	3.460	5.945	8.429	10.914	13.398	15.882	18.367
5	2.321	3.563	6.047	8.532	11.016	13.500	15.985	18.469
6	2.423	3.665	6.150	8.634	11.118	13.603	16.087	18.572
7	2.525	3.768	6.252	8.736	11.221	13.705	16.190	18.674
8	2.628	3.870	6.354	8.839	11.323	13.808	16.292	18.776
9	2.730	3.972	6.457	8.941	11.426	13.910	16.394	18.879
10	2.833	4.075	6.559	9.044	11.528	14.012	16.497	18.981
15	3.345	4.587	7.071	9.556	12.040	14.524	17.009	19.493
20	3.857	5.099	7.583	10.068	12.552	15.036	17.521	20.005
25	4.368	5.611	8.095	10.579	13.064	15.548	18.033	20.517
30	4.880	6.123	8.607	11.091	13.576	16.060	18.545	21.029
35	5.392	6.635	9.119	11.603	14.088	16.572	19.057	21.541
40	5.904	7.147	9.631	12.115	15.600	17.084	19.569	22.053
45	6.416	7.658	10.143	12.627	15.112	17.596	20.080	22.565
50	6.928	8.170	10.655	13.139	15.624	18.108	20.592	23.077

[1]Derived from: Pd = 0.566989 + 0.102391 A + 1.24220 D;
where, Pd = decay extent, in feet, below the dead-top base,
A = dead-top age in years,
D = diameter at base of dead top in inches, and
R^2 = 0.251.

Recommendations

This study suggests that in the Blue Mountains, grand firs with dead tops having basal diameters up to 2 inches will be practically free of associated decay, even after many years. Salvage or stand improvement operations should concentrate on removing trees with dead tops with large (>2") basal diameters to reduce future decay losses. Defect factors reported here will be useful as general guidelines to timber cruisers and markers in the Blue Mountains. They should not be relied upon in other areas where top-kill occurs because of possible variation in defect extent.

Secondary bark beetle and wood borer attack in dead tops greatly increases decay frequency and extent. Studies of population dynamics of beetles and borers in weakened trees and in damaged tops are needed. We need to know when attacks first take place, how long they last, the beetle populations, and the identity of bark beetles and wood borers.

We and others studying decay associated with dead tops have had difficulty isolating the hymenomycetous fungi causing decay. Apparently, faster growing, imperfect fungi, bacteria, and yeasts, probably associated with beetles, exclude the decay fungi from the culture media. Studies are needed to find: (1) antibiotics to suppress the growth of imperfect fungi and bacteria, and (2) isolation media which favors growth of decay fungi over their competitors.

Literature Cited

Etheridge, D. E., H. M. Craig, and S. H. Farris.
1976. Factors influencing infection and initiation of decay by the Indian paint fungus (*Echinodontium tinctorium*) in western hemlock. Can. J. For. Res. 6:299-318.

Graham, David A., Jack Mounts, and D. Almas.
1975. 1974 Cooperative Douglas-fir tussock moth control project, Oregon, Washington, and Idaho. USDA, For. Serv. Reg. 6, Pac. Northwest Reg., Portland, Oreg. 74 p.

Mounts, Jack.
1976. 1974 Douglas-fir tussock moth control project. J. of For. 74(2):82-86.

Wagener, Willis W., and Ross W. Davidson.
1954. Heart rots in living trees. Bot. Rev. 20(2):61-134.

Wickman, Boyd E.
1963. Mortality and growth reduction of white fir following defoliation by the Douglas-fir tussock moth. USDA, For. Serv. Res. Pap. PSW-7, 15 p., illus. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Wickman, Boyd E.
1978. Tree mortality related to defoliation by the Douglas-fir tussock moth in the Blue Mountains outbreak. USDA, For. Serv. Res. Pap. PNW-233, 47 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Wickman, Boyd E., and Robert F. Scharpf.
1972. Decay in white fir top-killed by Douglas-fir tussock moth. USDA, For. Serv. Res. Pap. PNW-133, 9 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

GPO 987-595

Aho, Paul E., Boyd E. Wickman, and Lee Roe.
1979. Decay in tops killed by Douglas-fir tussock moth in the Blue Mountains. USDA For. Serv. Res. Pap. PNW-250, 22 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Incidence of infection by fungi and decay loss was negligible in Douglas-firs with tops killed by tussock moth or bark beetle attack. Regardless of the cause of top-kill, both the percentage of grand firs infected and the associated decay volumes significantly increased with increasing basal diameter of dead tops. Severity of decay was not related to age of top damage. Decay was most severe when both bark beetles and wood borers attacked dead tops.

KEYWORDS: Decay (wood), insect damage (-forest, top-kill, defect indicators (wood quality), Douglas-fir tussock moth, *Orgyia pseudotsugata*.

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